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A Second Look at Jim's Scope Data

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Abstract

This note follows up on Beams-doc-922. The note presents the Fourier transform of the full data set, to look for noise levels and for betatron motion.

1 What I Did

Fig. 1 shows the magnitude of the Fourier transform of full time series, 763 turns, in the single bunch file:

Single_Proton_Store/sing_bunch_coal_250Ms_wfilt_A15_Ch1.mat

This file was taken with a sampling rate of 250 MHz and the signals were sent through a low pass filter, with a cut-off of 70 MHz, before they were digitized. The four plots in Fig. 1 show the same Fourier Transform but over different frequency ranges. All plots have a bin size of 10 Hz, regardless of the range of the plot.

To suppress noise, and speed things up, the FT was computed using only the 35 bins in each turn which contain the bunch signal. The phase was preserved over the full 763 turns. A later section will show the results when the FT is computed using all of the data in the turn, including the approximately 5200 data points with no bunch signal.

The top plot shows the FT over a range of 200 kHz, centered on the RF frequency. The rotation lines, separated by 47.7 kHz, are clear.

The second plot shows a window of 2kHz, centered on the RF frequency. The first minima from the central maximum are at ± 6 bins, or about ± 60 Hz. This is consistent with their expected position:

(53.1 MHz) / (1113 RF cycles/orbit) / (763 orbits) = 62.5 Hz

I guess we can learn something about the noise level by looking at how far the minima are from zero? To be serious about this I will need to do another run with finer bins.

The third plot shows the interval between two of the rotation lines in more detail.

The 4th plot is a repeat of the third plot but with the vertical scale changed so that we can focus on the data between the rotation lines.

2 What about betatron lines?

1. I did not expect to see any (see point 3) and I do not see them.

2. If they were present, I would see a pair of lines centered on the halfway point between each rotation line. Right?

3. We are looking at stable beam with no artificially induced betatron oscillations. Also, the betatron oscillations created by injection errors and any other beam manipulations have long since been traded for emittance growth. So I did not expect to see any betatron oscillations.

3 What about synchrotron lines?

I do not expect to see any for two reasons:

1. They should be absent for the same reason that the betatron oscillations are absent.

2. Even if they were present, the full time range of the data covers only about one period of the synchrotron oscillation. So I would expect the signal strength to be poor but I have not thought about this quantitatively.

4 Conclusions About Fig. 1

I think we can conclude from this that the resolution on (A-B)/(A+B) shown on pages 8 and 10 of Beams-doc-922 is not due to beam motion. So we are probably seeing the true limits of the technique. However this scope data has only an 8 bit ADC and we should get better resolution when we use a better ADC.

5 Keeping in all of the Noise

With one exception, Fig. 2 was produced the same way as Fig. 1. The difference is that Fig. 2 uses all of the data points in the file when computing the Fourier transform, while Fig. 1 uses only 35 bins from each turn in the neighbourhood of the bunch signal. Including all of the data is about 150 times slower and only adds noise. Therefore Fig. 1 shows a best case scenario for noise suppression, while Fig. 2 shows a worst case (again with the caveat that this is 8 bit data).

All of the main features in Fig. 1 are also present in Fig. 2. The most noticeable difference is that the noise floor is about 10 times higher in Fig. 2.

Fig. 3 shows a more detailed comparison of Fig. 1 and Fig. 2, focusing in on the region between the rotation lines, where the difference is most pronounced. The top plot in Fig. 3 is the bottom plot from Fig. 2 while the second plot is the bottom plot from Fig. 1. These two plots are drawn with the same vertical scale so that the difference is noise level is highlighted.

The third plot in Fig. 3 is the difference of the first two, first minus second, zoomed out to the full horizontal scale. The red horizontal line is drawn through zero on the vertical axis. We can see that, when all of the data is used, there is some loss of signal in all of the rotation lines, particularly in the line at 53.1037 MHz. This is a small change compared to the increase in noise level.

The fourth plot is a repeat of the third, but zoomed in on the horizontal axis to focus on the region around the RF frequency. This is the same range of frequency as was used for the second plots in Fig. 1 and Fig. 2. This shows that the loss of signal in the rotation line is real, not a binning artifact.

6 Conclusions from Figs. 2 and 3

Using all of the data still gives strong rotation lines. The noise level increases by about a factor of 10 and there is a small loss of signal strength.

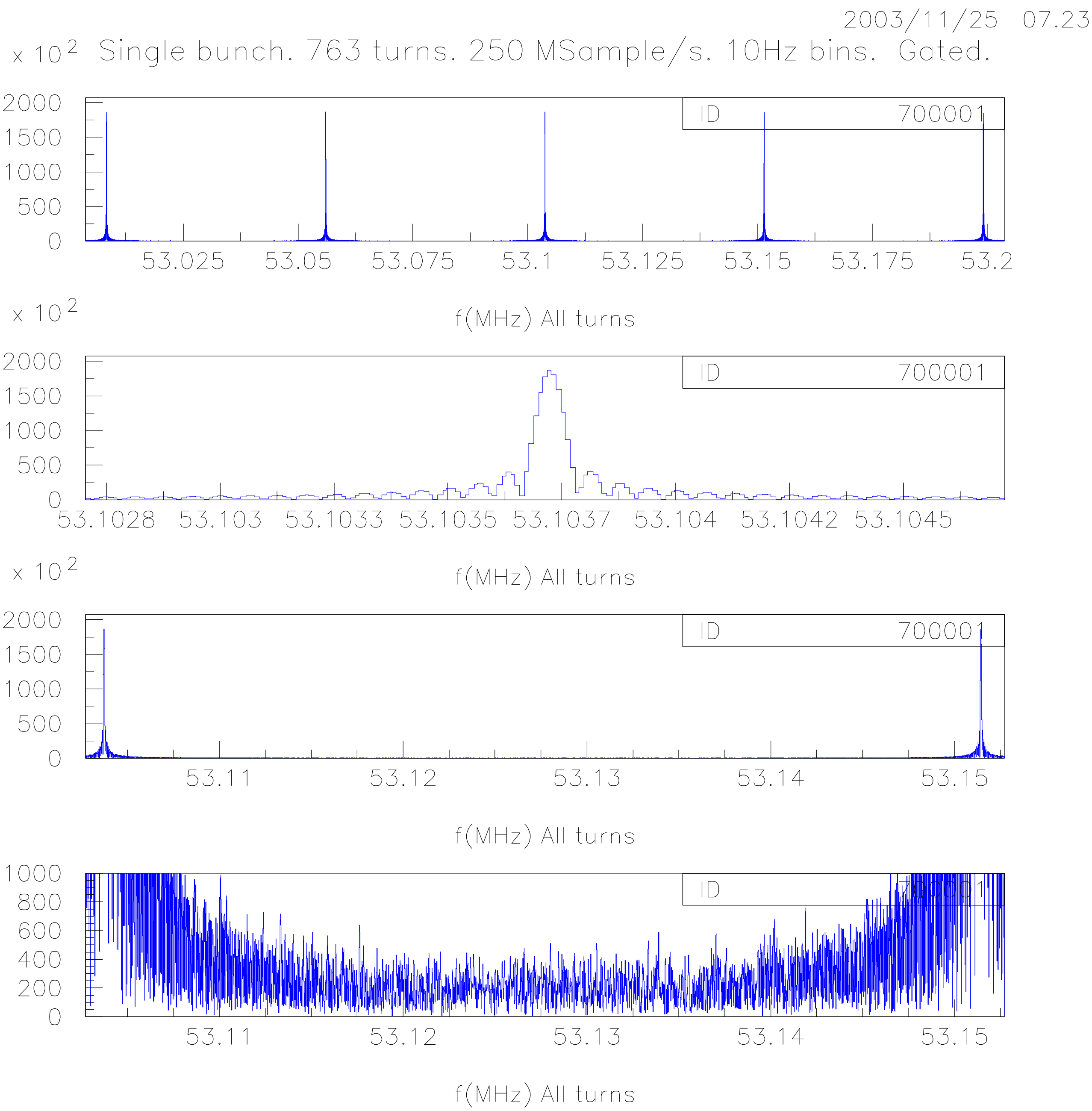

Figure 1: Fourier Transform of the single bunch data. The bin size is 10 Hz in all plots. The transform uses only data in the neighbourhood of the bunch signal.

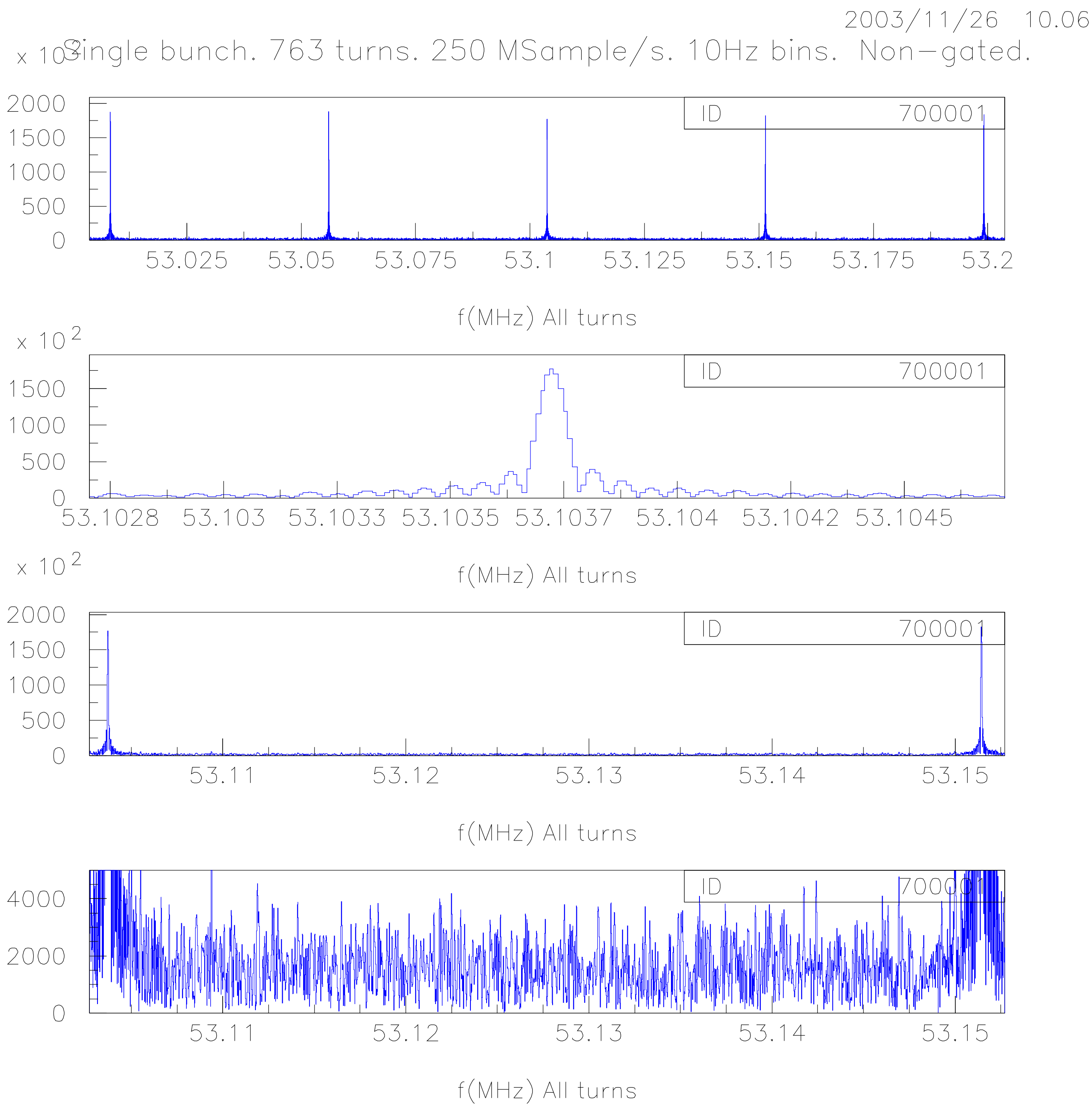

Figure 2: Fourier Transform of the single bunch data. The bin size is 10 Hz in all plots. The transform uses all of the data, including the noise far from the bunch signal.

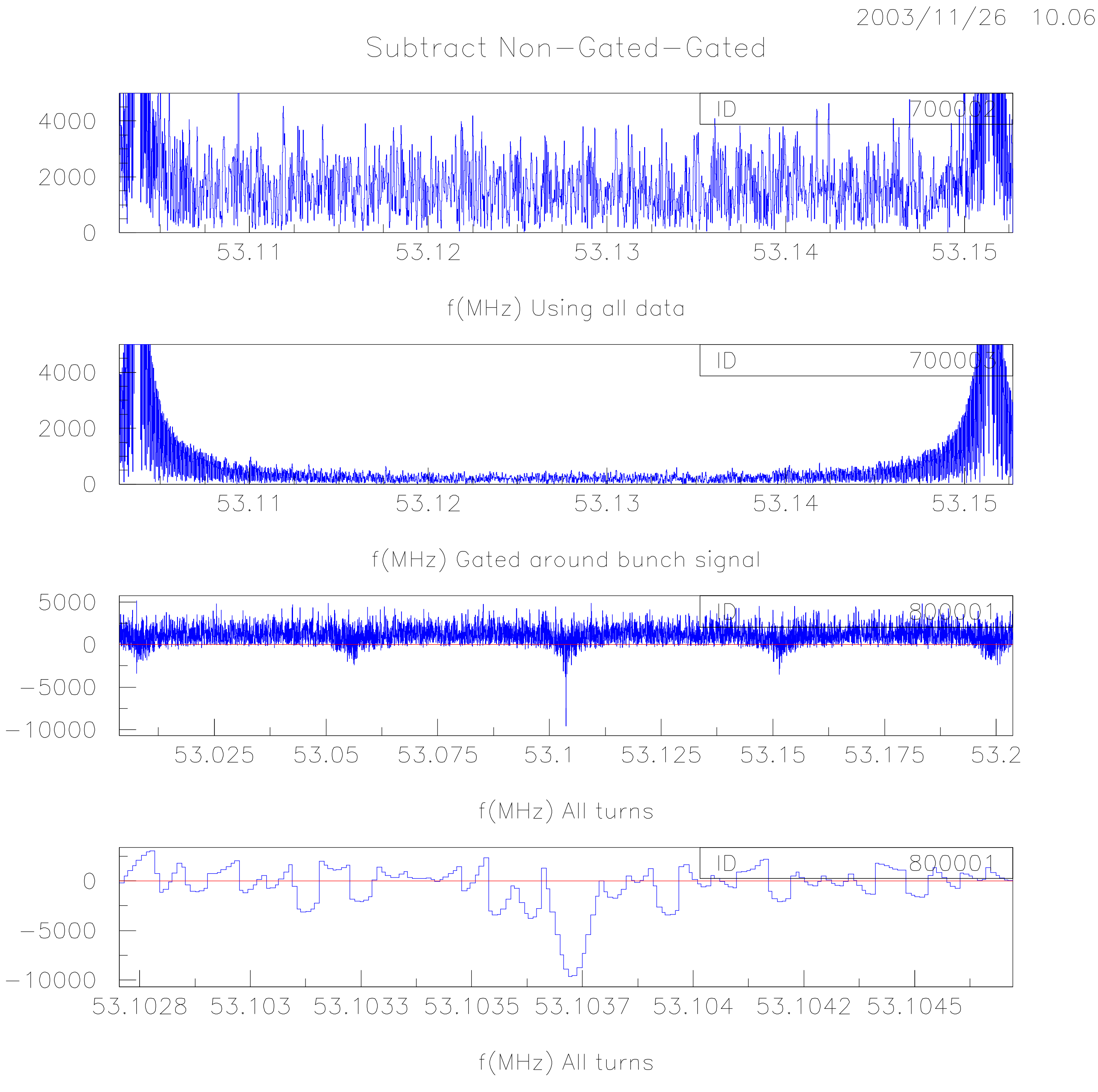

Figure 3: Comparison of the Fourier transforms: Fig. 2-Fig. 1.